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Dairy Lagoon Effluent Effects on Soil Chemical Properties, Corn Yield and Nutrient Uptake

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Abstract: This study evaluates the effects of dairy lagoon effluent application on selected soil chemical properties, corn yield and nutrient uptake for an active dairy farm in New Mexico. Three fields were selected for comparison. The first field had received lagoon effluent for three years whereas only manure and lagoon solids had been applied to a second field. The third field not as intensively cropped as the other two fields and was considered as a control. Total corn yield from field 1 was about 2.7 ton ha•^{1} higher than that of field 2. Nitrogen and Potassium removed by corn were slightly elevated by lagoon effluent application. For field 1, soil $EC_{1:5}$ values below 60 cm were relatively higher than that of field 2. Lagoon effluent application on field 1 indicated a 27% increase in NO_3-N in the profile below 90 cm.

Key words: Lagoon effluent, soil chemical properties, corn yield, nutrient uptake

INTRODUCTION

During the 1990s and 2000s, an expansion of the dairy industry occurred in the United States. Dairy industry expansions give rise to greater quantities of wastewater as a by-product of dairy operations. The wastewater generated from dairy operations contains elevated levels of nutrients including nitrogen (N), phosphorus (P) and potassium (K) and is stored in lagoons prior to land application. Land application is the treatment of wastewater by using plant cover, soil surface, soil profile and geological materials to treat certain wastewater pollutants. The benefit is not only to provide nutrients for plant growth, but also to provide a place for disposal and waste biodegradation. Furthermore, wastewater applied to soil can compensate for a water deficit situation in arid and semiarid areas and provide water for short-term drought in humid regions.

Nutrients in lagoon effluent applied to agricultural land to maintain crop quality at a high level of production may become pollutants if they are transported away from their place of application. Large inputs of N, while stimulating plant growth, can lead to increased nitrate-nitrogen (NO_3-N) in the soil profile which can leach beyond the crop root zone. Over application of lagoon effluent can also cause P accumulation in soil and when runoff and soil erosion occur, P can reach nearby surface waters[1-4].

Due to increased concern over the effect of animal wastewater on the environment, there has been an increased effort by scientists to determine the effects of wastewater usage on soil and plant response. The objective of this study was to evaluate current management effects of lagoon effluent application on selected soil chemical properties, corn (*Zea mays* L.) yield and nutrient uptake for an active dairy farm.

MATERIALS AND METHODS

Site description: A dairy farm, located about 30 miles north of NMSU-ASC at Artesia (32?50'32" N, 104?24'10" W), was chosen as a case study. As test cases, two fields were selected on the dairy and one next to the dairy farm for comparative purposes. The first field had received a mixture of freshwater and lagoon effluent for three years in addition to lagoon sludge in 1999. Dairy manure and sludge had been applied to the second field but there had been no lagoon effluent application. Fresh well water was used for irrigation of this field. Silage corn was grown on both field 1 and 2. The third field was not as intensively cropped as the other two fields. All evaluated fields were on a Reagan loam (fine, carbonic, thermic, Typic Calciorthid) with a 0-1% slope[5].

Soil sampling: A 5.1 ha area of each field was soil sampled in a grid pattern every 30 m for a total of

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72 cores per field. Soil cores were portioned into 15 cm increments down to 30 cm and then in 30 cm increments between 30 and 180 cm. Soil samples were collected at the beginning and end of the corn season from field 1 whereas fields 2 and 3 were sampled after corn harvest only. All soil samples were analyzed for electrical conductivity (EC) and NO_3-N.

Plant sampling: Plant samples were collected from 1 m of row by cutting the plants 6 cm above the ground when they were nearly mature (one-third to two-thirds hard dough down the kernel) typical of a silage harvest system. These samples were taken from only 36 of 72 grid locations of field 1 and 2. For each grid point, dry matter yield was calculated. The plant tissue samples were analyzed for total-N[6], P[6] and K[7] concentration. For each grid point, crop nutrient uptake for N, P and K were also calculated.

RESULTS AND DISCUSSION

Selected soil chemical characteristics: Soil texture varied between clay loam and sandy clay loam for the 0-60 cm soil profile and was clay below 60 cm for all three fields. Box plots for soil $EC_{1:5}$ and soil NO_3-N with depth from each field demonstrate the amount of field variability for these parameters (Fig. 1 and 2). It is important to note that in box plots, the boxes encompass 50% of the observed values and the capped bars encompass 90% of the observations. Median soil $EC_{1:5}$ values generally increased with increasing depth for all three fields. There were small variations in soil $EC_{1:5}$ in the corn root zone (0-60 cm). Below the corn root zone, variations in soil $EC_{1:5}$ for the 72 grid points of each field were relatively large compared to the surface soil. This was probably due to the change in soil texture. Therefore, an asymmetric distribution was observed for the subsoil $EC_{1:5}$ values (Fig. 1). Median soil $EC_{1:5}$ values by depth ranged from 0.69 to 2.29 dS m^{-1} for the initial samples (Fig. 1a) whereas this range for ending soil samples was between 0.39 to 2.25 dS m^{-1} (Fig. 1b) in field 1. For the active root zone in field 1, ending soil $EC_{1:5}$ values were less than that of initial soil samples probably due to application of lagoon effluent to the field before initial soil sampling, crop removal and leaching during the growing season. Compared to the ending condition of field 1 (Fig. 1b), median soil $EC_{1:5}$ values for field 2 (between 0.38 to 1.33 dS m^{-1}) were relatively low below the first 60 cm (Fig. 1c). This may have been the result of the wastewater application which had an $EC_{1:5}$ of 3.8 dS m^{-1}. Similarly, Evans *et al.*[8] observed large increases in electrical conductivity with lagoon effluent applications. Since the difference was observed in the subsoil, leaching may have been one pathway for this difference to have occurred. However, the third field, which was not as intensively cropped as the other two fields, had similar median $EC_{1:5}$ values (Fig. 1d) for ending conditions $EC_{1:5}$ as field 1 (Fig. 1b). Considering soil $EC_{1:5}$ values for all three fields, it can be concluded that water management was similar among the fields and effluent water contributed little to the change in soil $EC_{1:5}$.

Unlike soil $EC_{1:5}$ values soil NO_3-N expressed as a fraction of the total profile NO_3-N for the initial (Fig. 2a) and ending (Fig. 2b) samples from field 1 decreased with increasing soil depth. The highest median value for field 1 was observed in the surface 15 cm of the profile for initial (219 mg kg^{-1}) and ending (87 mg kg^{-1}) soil samples. Compared to the 150-180 cm soil depth, relatively small changes (ending – initial) were observed for the 60-150 cm soil depth. The change at 150-180 cm (80 kg NO_3-N ha^{-1}) suggests NO_3-N leaching from upper soil depths of field 1 as a result of effluent application. Similar conclusions were drawn by King *et al.*[1,2], Liu *et al.*[3] and Evans *et al.*[8]. They concluded that each year an accumulation of NO_3-N was evident in the subsoil and heavy application of lagoon effluent could have environmental implications for the quality of soil, groundwater and surface runoff.

Total NO_3-N content of the active root zone ranged from 400 to 1800 kg NO_3-N ha^{-1} for the initial samples from field 1. For the ending soil samples, this range was between 200 and 900 kg NO_3-N ha^{-1}. The difference in NO_3-N content at the crop root zone between initial and ending samples is probably due to crop N uptake and NO_3-N leaching from upper soil depths.

Compared to field 1, relatively small variation was observed in soil NO_3-N among soil depths for field 2 and 3 (Fig. 2c and d). The highest concentration was 57 mg kg^{-1} in the top 15 cm of soil in field 2. Approximately 720 kg NO_3-N ha^{-1} was present in the sampled profile. About 48% of this was in the top 60 cm of the field 2. Total amount of NO_3-N in the active root zone ranged from 175 to 547 kg NO_3-N ha^{-1}.

Unlike the other two fields, field 3 soil NO_3-N content slightly increased with increasing soil depth (Fig. 2d). Approximately 932 kg NO_3-N ha^{-1} was present in the sampled profile. Only 23% of this was in the top 60 cm of field 3. Total NO_3-N content in the 0-60 cm depth ranged from 134 to 436 kg NO_3-N ha^{-1}. Similarly, soil NO_3-N content in the 60-180 cm depth ranged from 322 to 1064 kg NO_3-N ha^{-1}. No fertilizer or manure was added to field 3 prior to sampling in 1999 which suggests that the NO_3-N in soil could be related to nitrogen loading from inorganic sources from prior years.

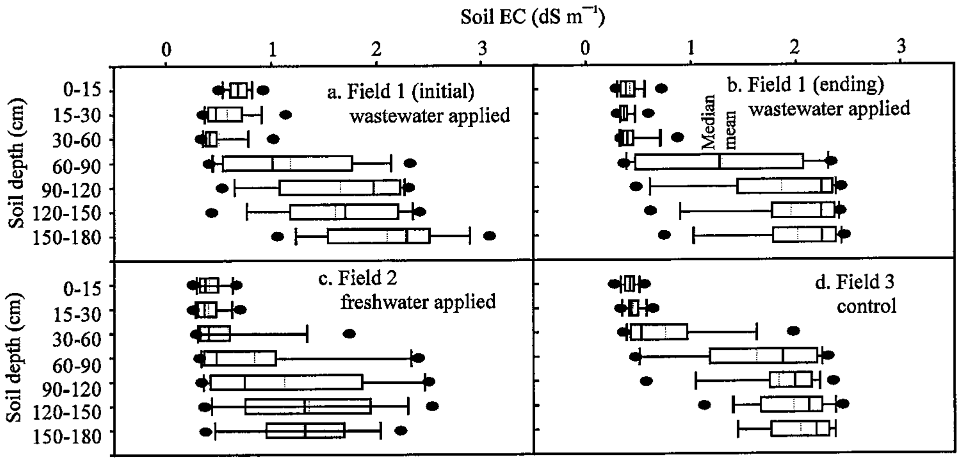

Fig. 1: Box plots for soil EC $_{1:5}$ with depth

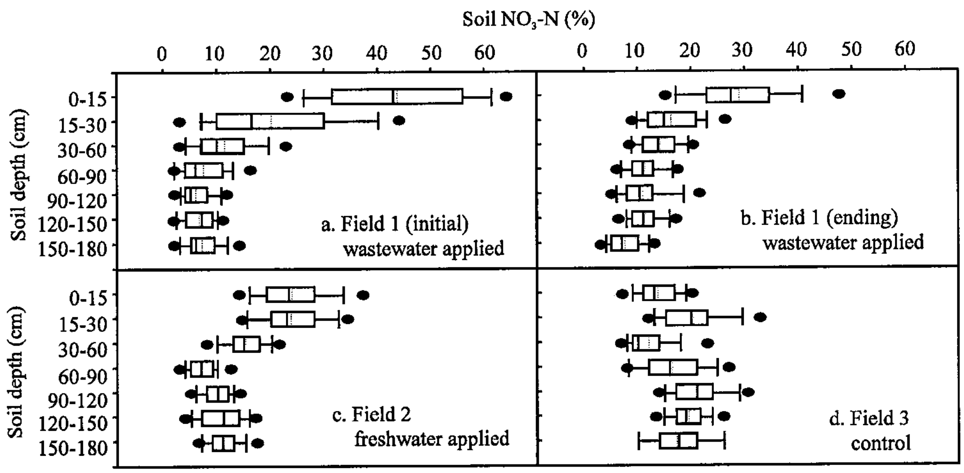

Fig. 2: Box plots for soil NO_3-N expressed as a fraction of the total profile NO_3-N

Table 1: Summary statistics from 36 sampled locations within fields 1, 2 and 3 for corn yield and nutrient removal

		Statistics				
		Min.	Max.	Median	Mean	Std. Dev.
Field	Var.	----------	----------	kg ha⁻¹	----------	----------
1	Yield	13,100	31,440	23,580	24,017	4,749
	N	127	572	336	350	91
	P	22	79	50	52	13
	K	170	490	336	345	78
2	Yield	10,480	28,820	20,960	21,324	4,114
	N	152	406	303	304	960
	P	17	73	50	48	12
	K	147	458	313	318	67

Corn yields and plant tissue: Summary statistics for yield response, N, P and K removal by corn as related to field are given in Table 1. Yield ranged between 13.1 to 31.4 metric ton ha^{-1} with a mean value of 24.0 metric ton ha^{-1} for field 1 whereas the range was 10.5 to 28.8 metric ton ha^{-1} with a mean value of 21.3 metric ton ha^{-1} for field 2 (Table 1). The dairy reported that yields from the field 1 and 2 were 24.2 and 21.7 metric ton ha^{-1}, respectively. In general, yield from field 1 was greater than that of field 2 by an average of 2.7 metric ton ha^{-1}.

For field 1, N removal ranged from 127 to 572 kg N ha^{-1} whereas the range was 152 to 406 kg N ha^{-1} for field 2. Field 1, that received effluent, removed an average of 45 kg N ha^{-1} more than field 2 (Table 1). Similarly, P uptake by corn ranged from 22 to 79 kg P ha^{-1} for field 1 and 17 to 73 kg P ha^{-1} for field 2. The mean values were 52 and 48 kg P ha^{-1} for field 1 and 2, respectively (Table 1). There was approximately 1:1 correlation between K and N uptake by corn for both fields. The mean values were 345 kg K ha^{-1} for field 1 and 318 kg K ha^{-1} for field 2. However, the difference in K uptake by corn (27 kg K ha^{-1}) was relatively lower than the difference in N uptake (45 kg N ha^{-1}) from field 1 and 2 (Table 1). Similar results reported by Evans *et al.*[8] and Sutton *et al.*[9] concluded that liquid manure applications significantly increased the corn yields and N, P and K levels in the plant tissue and grain.

Compared to field 2, lagoon effluent on field 1 over the past three years showed a 27% increase in NO_3-N in the profile below 90 cm and indicates a need to improve irrigation water management and/or nitrate loading to the field. Improvements should include decreasing the N content of the lagoon effluent and reducing effluent loading to the field. Furthermore, light and frequent irrigations is suggested instead of heavy and infrequent irrigations. Increased land area for lagoon effluent application would also be helpful for lagoon effluent management.

As a result, environmental concerns about nutrients in wastewater make the application of wastewater at high rates to agriculture land increasingly unattractive. Heavy application of lagoon effluent can cause potential hazard by N leaching. However, land application of dairy lagoon effluent to cropland in southeastern NM can be an effective means of treatment and environmentally sound with respect to N pollution when application rates based on TKN concentration of the lagoon effluent was matched to the crop nutrient removal. Soil and effluent analyses and proper estimation of yield goals are necessary to calculate agronomic application rates of lagoon effluent. Nutrient management practices determine if lagoon effluent is a benefit or a detriment to soil and water resources. These practices require management of both production goals and environmental considerations. Therefore, producers should develop a nutrient plan that maximizes the use of available manure nutrients while protecting the land from over fertilization.

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